DARPA Technology Interchange Meeting

S A M P S O N

SAMPSON Program Overview

26 June 2000

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Agenda

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SAMPSON Overview (charts 1-4)	**Ed White**
Core Technology	**Jeff Hall**
Marine Application (chart 5)	**Jeff Hall**
Aircraft Application (chart 5)	**Ed White**

SAMPSON Mission Statement and Program Objectives

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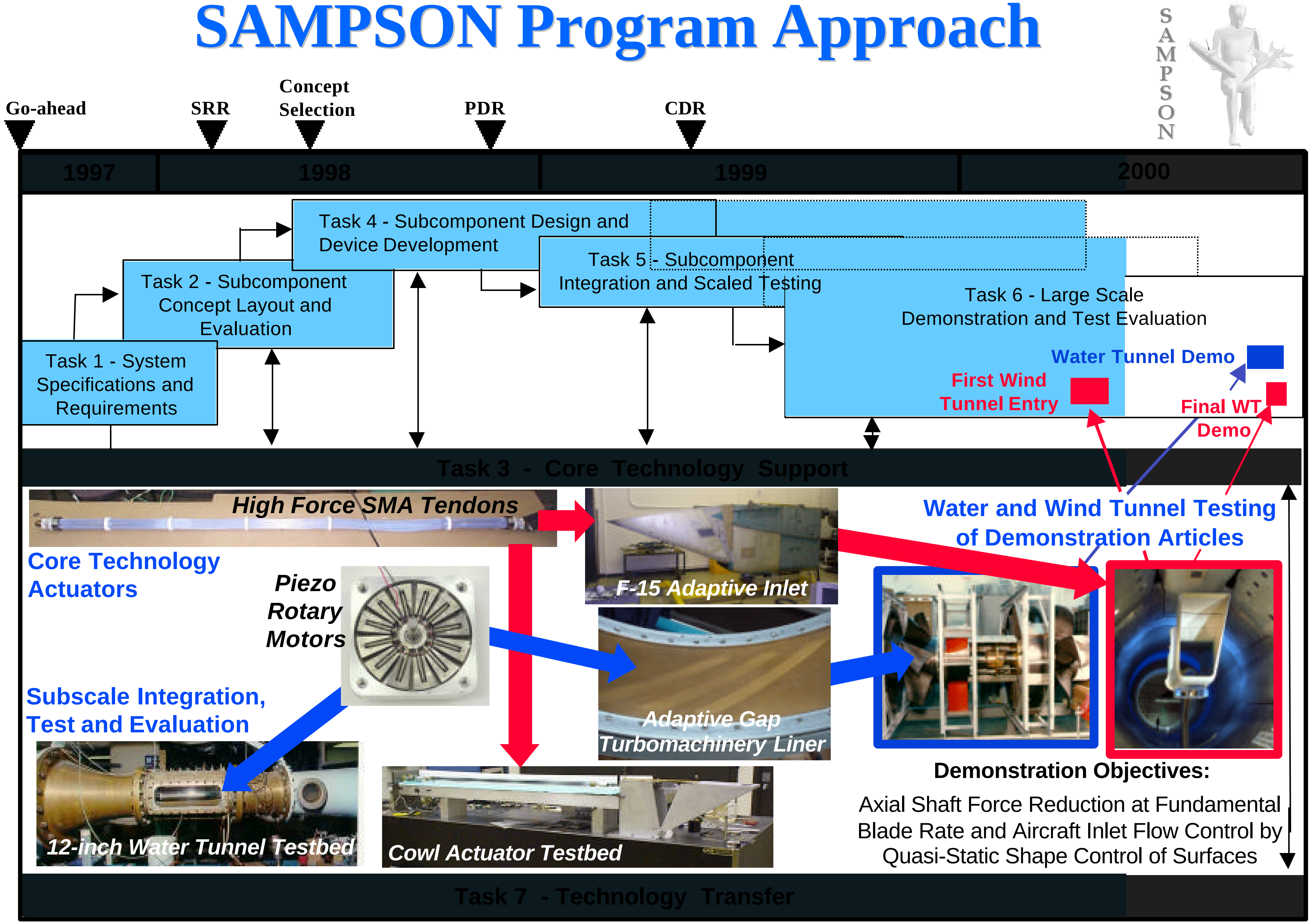
The SAMPSON program will use Smart Materials based Submarine component and Aircraft inlet demonstrations as development tools to expand and demonstrate the ability of Smart Structures Technology to provide significant expansion of vehicle operating envelopes to enable new missions.

Program Objectives:

- Demonstrate a full scale fighter aircraft inlet with highly integrated Smart Structures capable of providing more than a 20% increase in mission radius relative to conventional fixed inlet design
- Demonstrate a reduction in acoustic radiation of a submarine component in reduced scale water tunnel testing

Program Goal: Demonstrate Smart Structures benefits by <u>maximizing</u> the integration of actuators with structure

SAMPSON Program Approach



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The SAMPSON Team

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Program Sponsor/Monitors

DARPA
Ephrahim Garcia

IDA
Janet Sater

Pat Purtell

Jeff Flamm

Technology Insertion Board
NAVY, USAF, NASA

SAMPSON Consortium

Ed White
Program Facilitator

Dale Pitt
Aircraft Program Manager and Principal Investigator

PENNSTATE
Gary Koopmann (CAV)
Core Technology Leader
Mike Jonson (ARL)
Marine Demonstration

GENERAL DYNAMICS
Electric Boat
Jeff Hall
Marine Program Manager

Principal Subcontractors and Laboratories

Bernie Carpenter
Shape Memory Alloy Actuators

Georgia Tech Research Corporation
Ari Glezer
Synthetic Jet Technology

NAVSEA CARDEROCK
Surface Warfare Center Division
Charles Dai
Marine Applications Analysis and Testing

GTE
BBN Technologies
Tony Galaitsis
Marine Applications Control Technology

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SAMPSON Team Effort

Participant	Tasks	Status
Boeing	Consortium Lead Aircraft Inlet Demo Lead Aircraft Integration	First wind tunnel entry complete Designing components for second entry
Georgia Tech	Synthetic Jets / MEMS Orifices	Tasks completed
Lockheed Martin	SMA Actuation Systems	Supplying SMA for Aircraft and Marine Demos
Electric Boat	Marine Demo Lead Marine Demo Analysis Submarine Integration	Wind-tunnel and preliminary water-tunnel tests complete
BBN	Marine Acoustic Control System	Control hardware fab in work
Penn State		
CAV	Core Technology Lead	Rotary Wedge-worm fab ongoing
ARL	Marine Acoustic Demo	Preliminary Water-tunnel tests complete
NSWC/CD	Marine TAC Demo	Water-tunnel testing ongoing

Major Accomplishments Since Jun 99

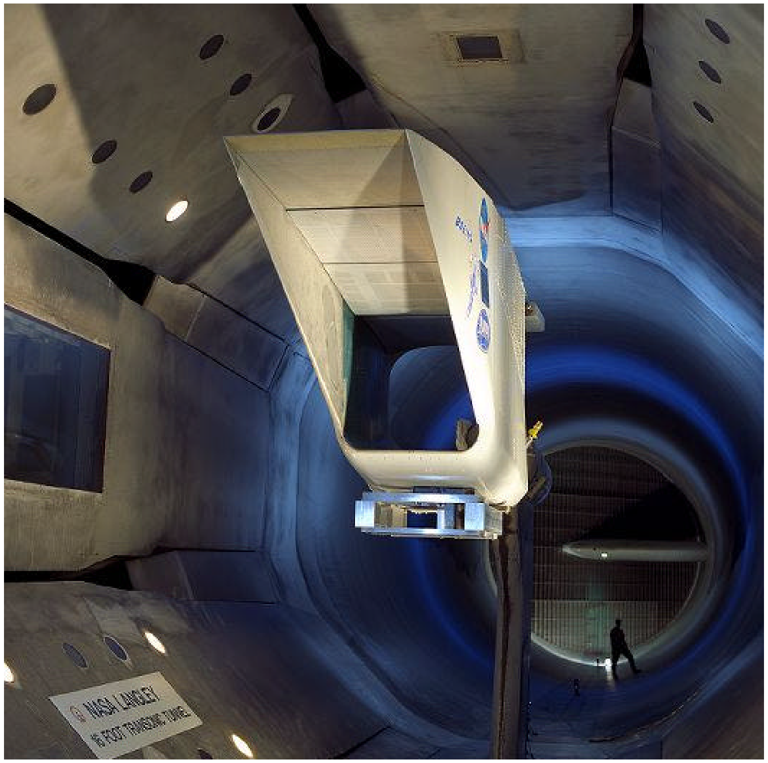
- **Completed fab and testing of four cowl rotation actuators using SMA tendon actuator capable of 6 in displacement and 12 kips force**
- **Completed design, analyses and fab of modifications to F-15 inlet for first wind tunnel entry**
- **Completed integration of cowl rotation actuators into F-15 inlet**
- ***Completed first entry of SAMPSON inlet in NASA Langley 16-Ft Transonic Tunnel - <u>All test objectives were successfully met</u>***
- **Completed 3rd preliminary water-tunnel tests at PSU/ARL**
- **Completed design of Marine Application demo mods to HIREP**
- **Completed design of rotary wedgeworm motors for Marine application demo**

Aircraft Application

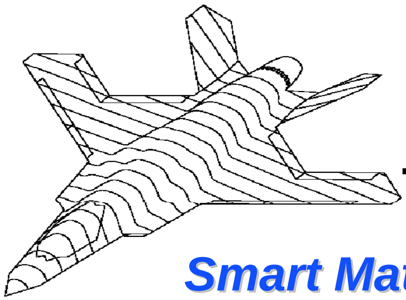
SAMPSON

<u>Objective</u>: ***Demonstrate geometry variation of a full-scale fighter aircraft engine inlet***

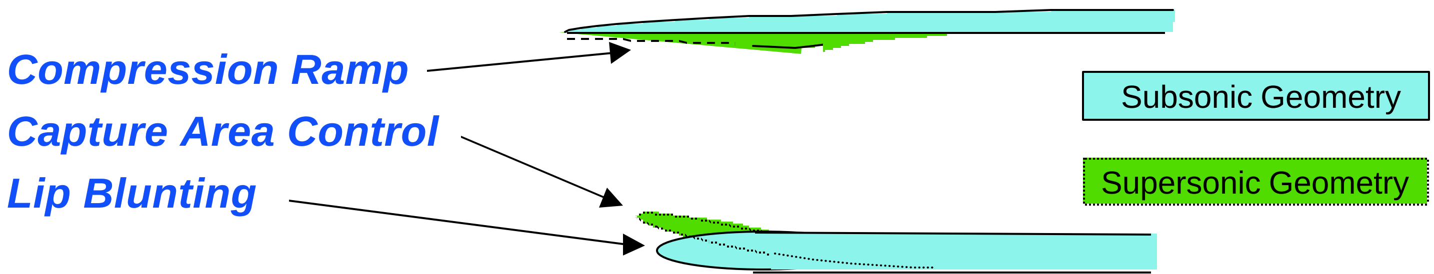
- **Capture area control**
  - Ý **Cowl actuation**
  - Ý **Lower lip rotation**
- **Lip bluntness control**
- **Wall shape control**



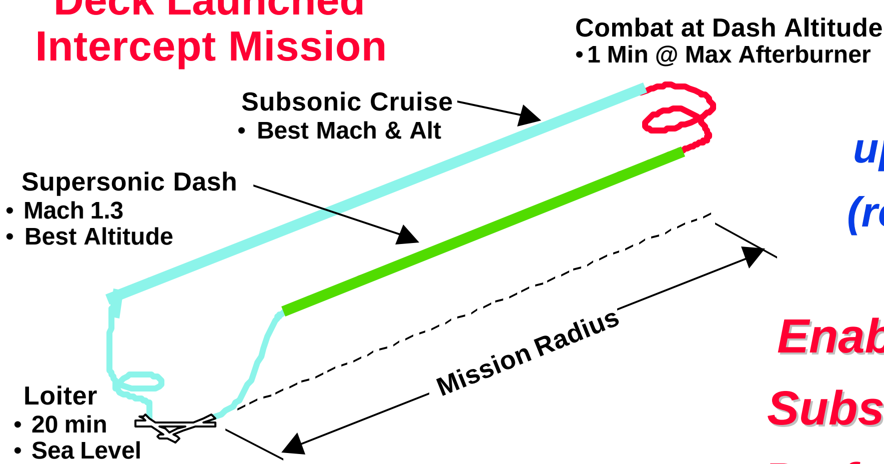
Variable Geometry "Smart Inlet" Expands Mission Envelope



Smart Materials Actuated Variable Geometry Inlet Provides:



Deck Launched Intercept Mission



Variable Geometry Inlet Provides

up to 20% Increase in Mission Radius

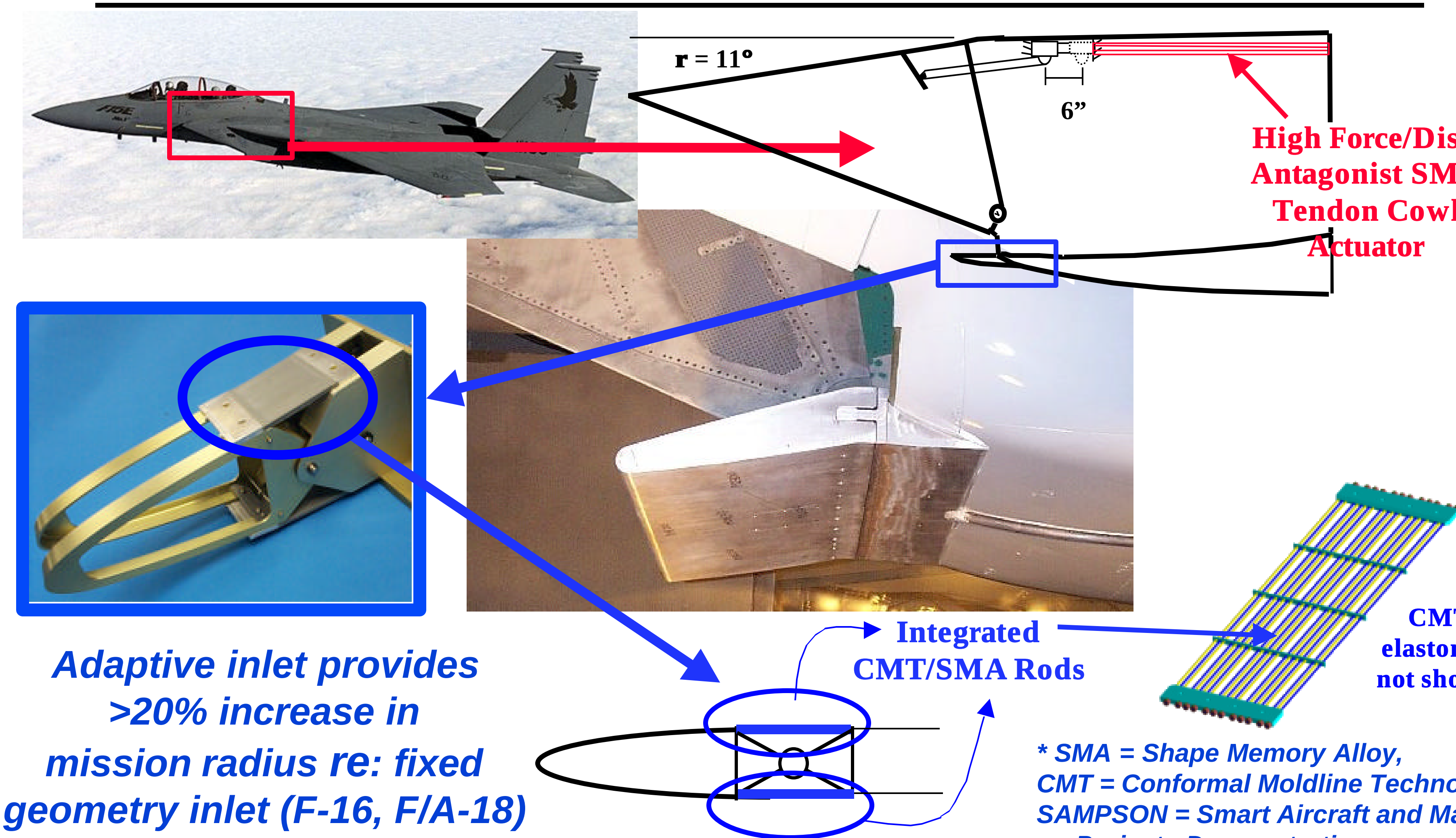
(relative to fixed inlet baseline design)

Enables Strike Aircraft Optimized for

Subsonic Interdiction Mission to Also

Perform Supersonic Intercept Mission

Capture Area Control Actuation

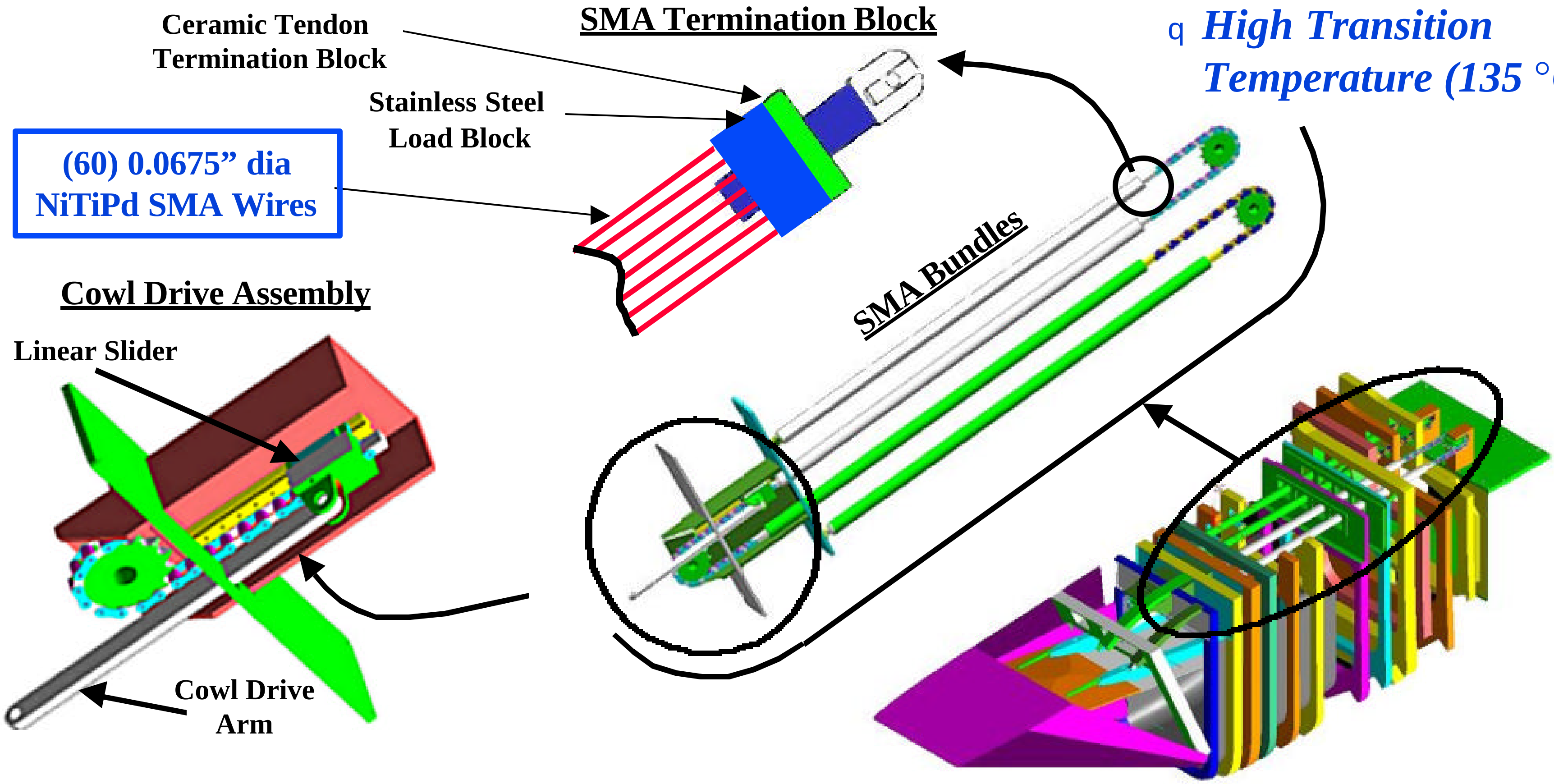


Adaptive inlet provides >20% increase in mission radius re: fixed geometry inlet (F-16, F/A-18)

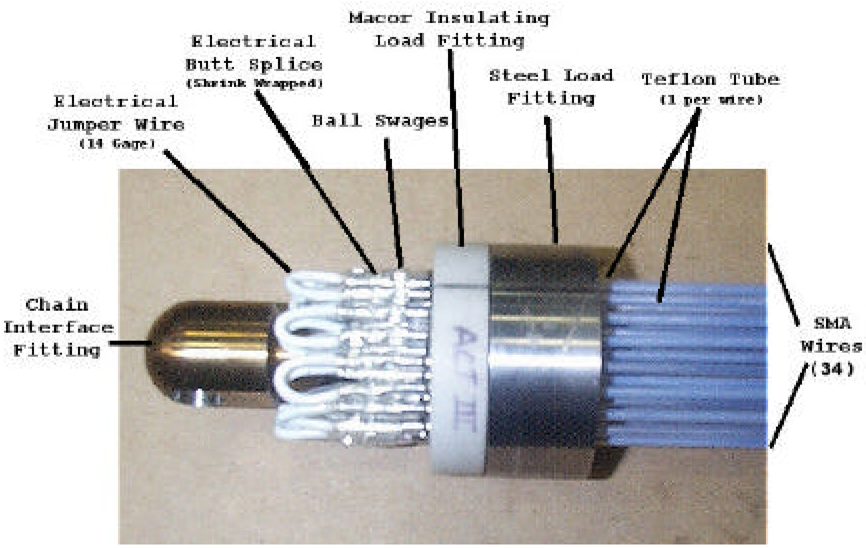
** SMA = Shape Memory Alloy,*
CMT = Conformal Moldline Technology
SAMPSON = Smart Aircraft and Marine Projects Demonstration

Cowl Actuation System

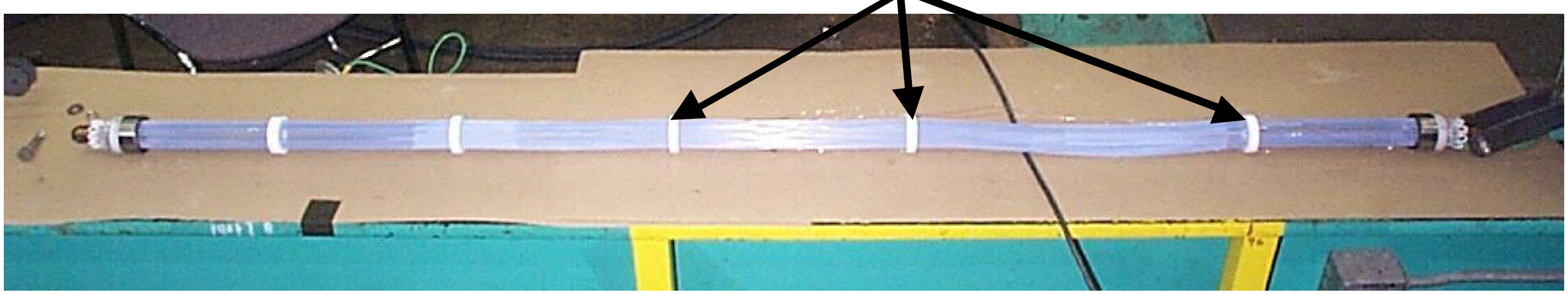
- *Up to 20,000 Lbs Force*
- *6 inches Displacement*
- *High Transition Temperature (135 °C)*



SMA Cowl Actuators



- 34 SMA NiTi Wires per Bundle
- Each Wire 68 mil Dia., 75” Long
- Bundle Force ~ 6000lbs (conservative)
- Displacement ~ 3” (at 4% Strain)
- Transition Temperature of 70º C
- Each Wire Electrically Isolated
- Teflon Spacer Blocks used for Collimating of Wires



Nothing is Easy

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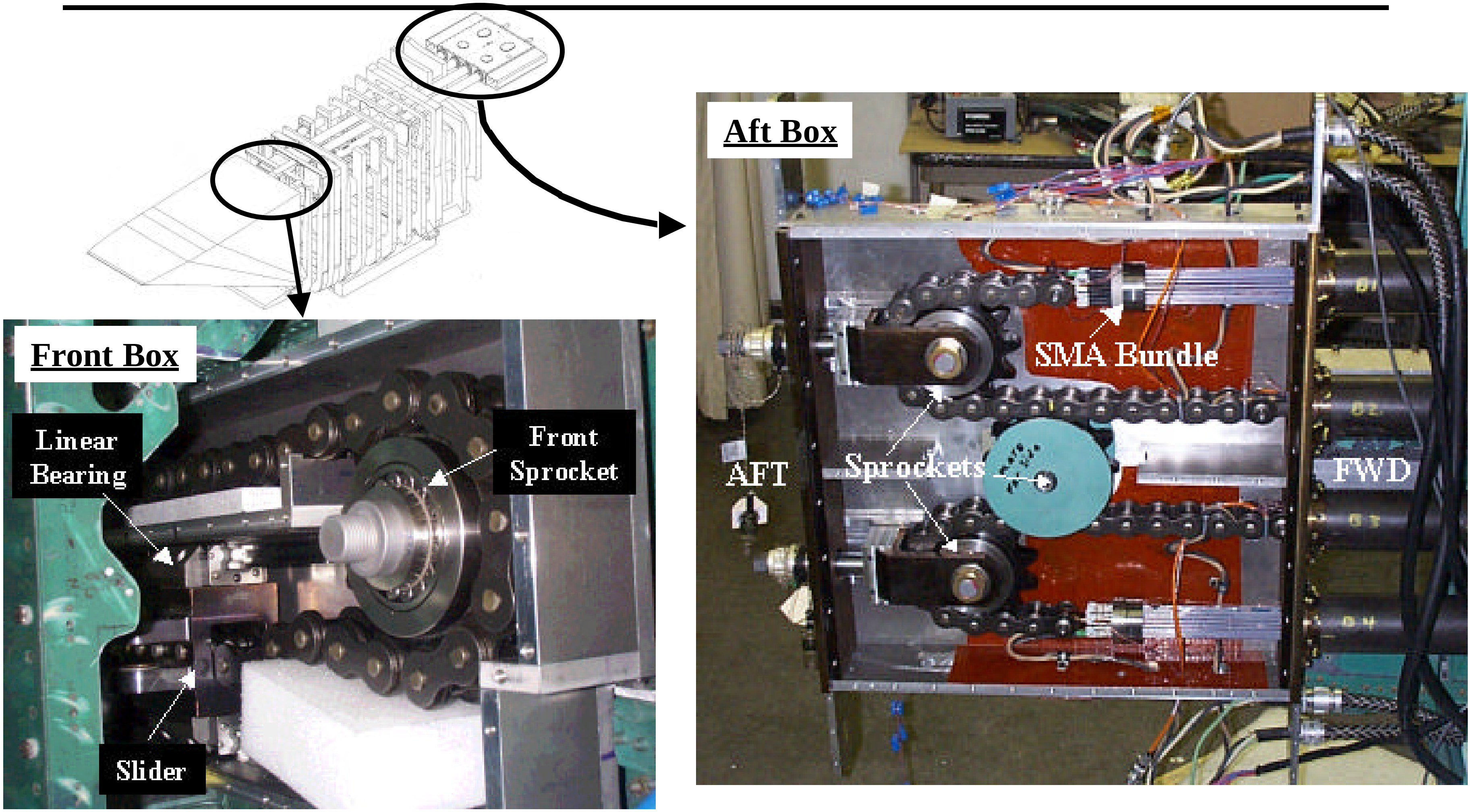
- First entry used binary NiTi because NiTiPd was not ready
  - Attempted to use 90 deg C binary material
  - Massive creep occurred in first bundles, including large 2-way SMA effect and highly non-uniform response of wires
  - Problems initially attributed to temperature non-uniformity
  - Backed-off on force (reduced wires to improve temp. uniformity) and pre-strain (4% down to 3%)
  - Changed to 70 deg C binary material - performance was excellent
  - However, tunnel heating limited testing time above Mach = 0.5 due to low transition temperature and limited effectiveness of cooling
- Palladium doped SMA is proving difficult to manufacture
  - High Temperature ductility appears to be 1/2-1/3 that of NiTi
  - However, initial DSC results look very good (low hysteresis)

Cowl Actuation System



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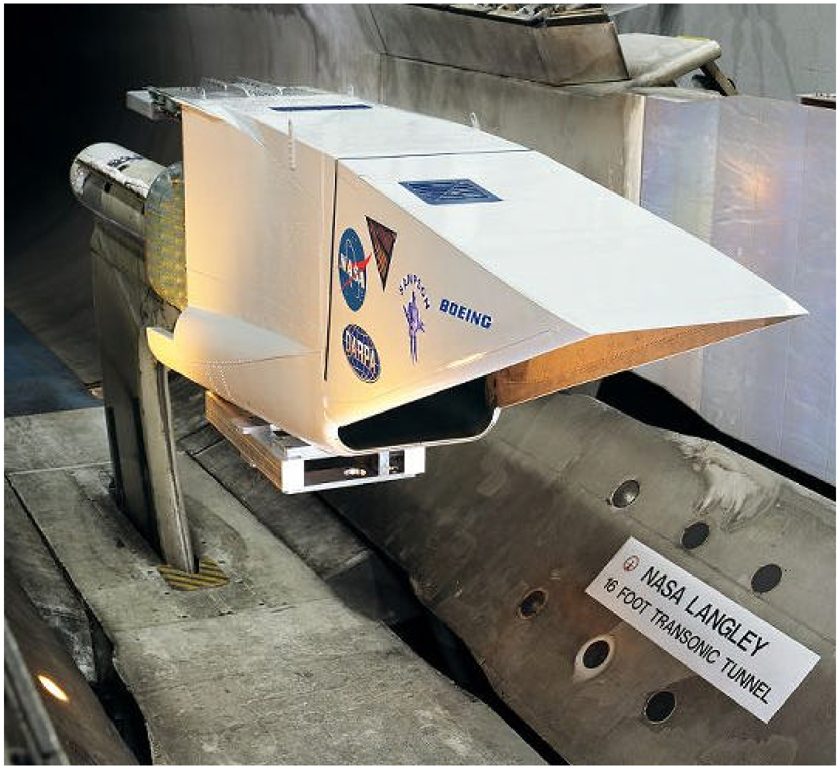
SAMPSON First Wind Tunnel Entry
April 26 through May 5, 2000



First Wind Tunnel Entry Objectives

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- **To validate the design air loads and identify angle of attack and angle of sideslip which minimizes loads applied to the sting and mounting structure.**
- **To provide a preliminary evaluation of the performance of the cowl actuator and uncover any problems to be corrected for the second entry.**
- **A secondary objective was to measure pressure distributions on the extended lower lip to support design of the adaptive lower lip to be demonstrated in the second entry.**

All Test Objectives Were Successfully Met

First Entry Results

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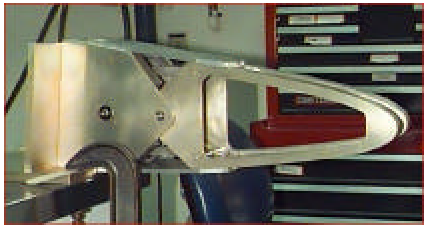
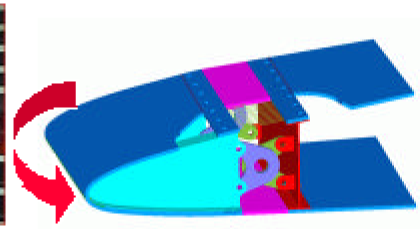
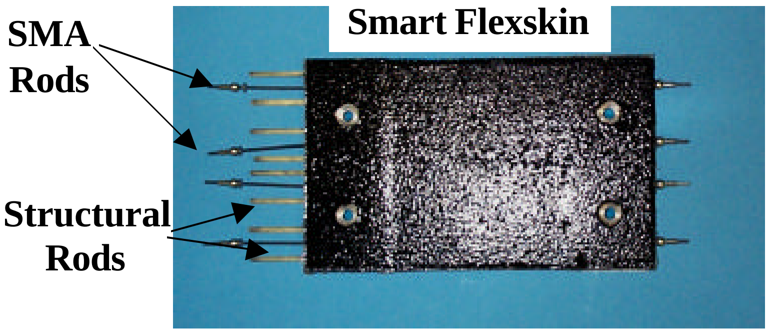
- **SMA bundle actuation system successfully integrated into F-15 Inlet**
- **Optimal AOA/Beta condition identified (AOA -4^{o} ; Beta -2^{o})**
- **Design loads verified and maximum Mach number identified (0.7)**
- **Successful cowl actuation at Mach 0.3 through 0.7**
  - **Max Load reached ~3500lbs at Mach 0.7**
  - **Cowl rotated between 2^{o} and 9^{o} (Bundles only stretched 3% initially)**
  - **Actuation Time on the order of 30 seconds**
  - **Actuation Power Used ~ 1700Watts per Bundle**
- **Effectiveness of active cooling of SMA was limited**
- **Open loop control was completely effective**
- **Pressure data gathered for second entry component locations**
- **Worked out issues of model installation, power, wiring, etc.**
- **Used only two weeks of slated three week entry**

Second Entry Plans

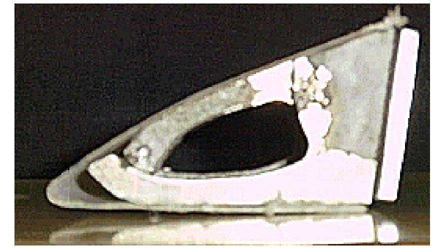
Lip Deflection

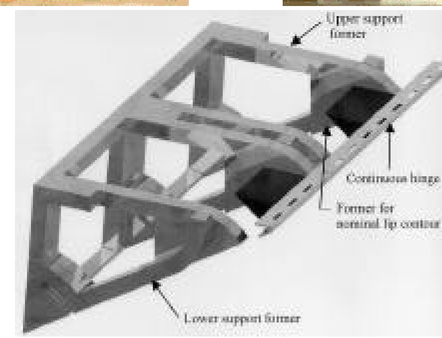




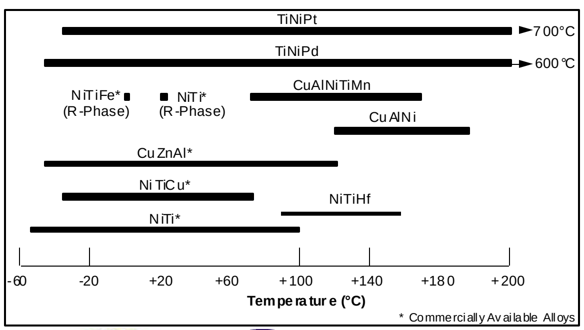


Lip Blunting

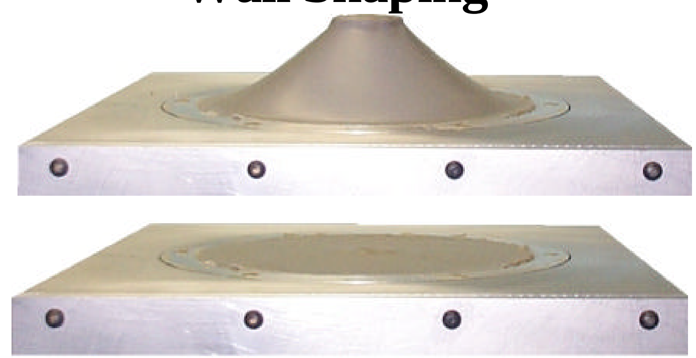




High Temperature SMA



Wall Shaping



Aircraft Demo Transitions

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- **Transitions Under Study:**
  - *Advanced Fighter Inlet Study*
  - *UAV/UCAV Advanced Concepts (primarily wing)*
  - *UEET Task 20 - NASA Langley*
  - *Advanced Commercial Aircraft Wing Component Studies*
- **Expected Program Accomplishments:**
  - *First full-scale demonstration of smart materials to provide large forces and displacements*
  - *First integration of SMA rod actuators within compliant structure configurations*
  - *First applications demo of NiTiPd, high temperature SMA*

SAMPSON Marine Mission Statement and Objectives

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The SAMPSON Marine program will use Smart Materials in turbomachinery and control surface demonstrations as development tools to expand and demonstrate the ability of Smart Structures Technology to provide potential mission enhancement.

- **Program Objectives:**
  - ➢ *Demonstrate a reduction in noise of turbomachine in water tunnel testing - Led by PSU/ARL*
  - ➢ *Demonstrate control surface actuation not possible without the use of smart material actuators - Led by NSWC/CD*
- **Program Goal: Demonstrate Smart Structures benefits by maximizing the integration of actuators with structure**

Turbomachinery Blade Passing Frequency(BPF) Noise

- Occurs when spatially non-uniform flow enters a turbomachinery blade row such as a fan rotor.
- The spatially non-uniform flow becomes unsteady and generates a local unsteady lift which manifests itself as a net unsteady thrust.
- At low frequency the unsteady thrust excites the structure directly through a thrust bearing.
- All of resulting sound or vibration occurs at BPF and multiples.

Gap Variation

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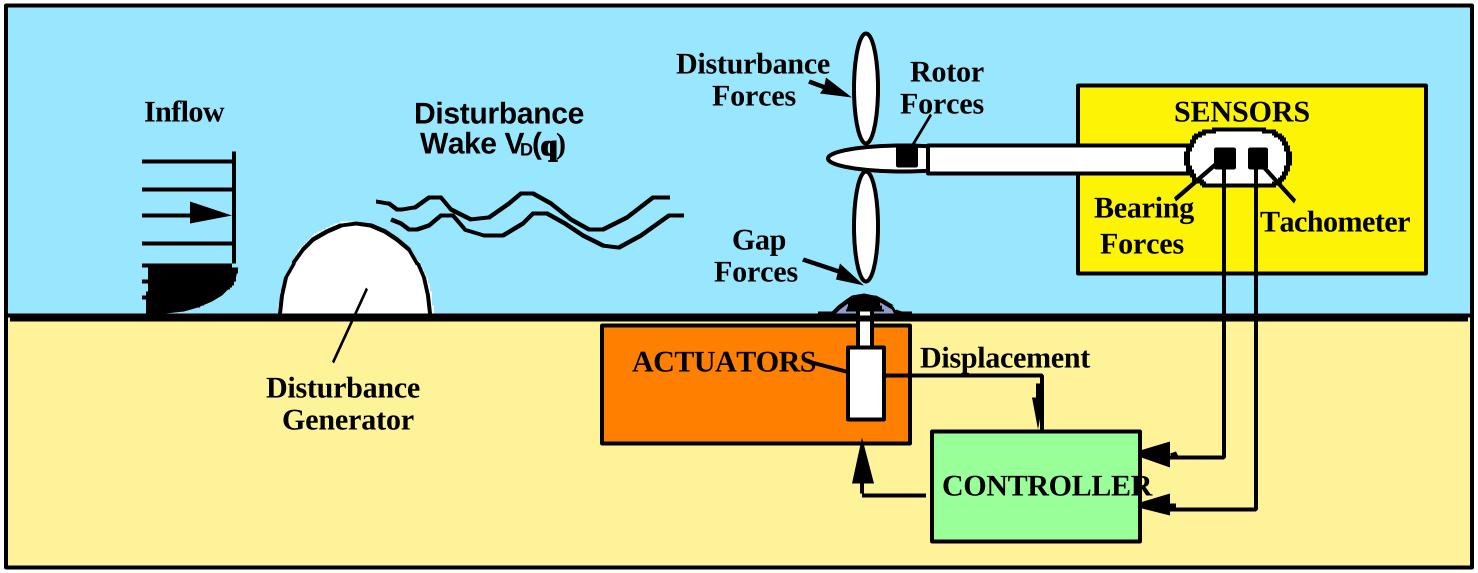
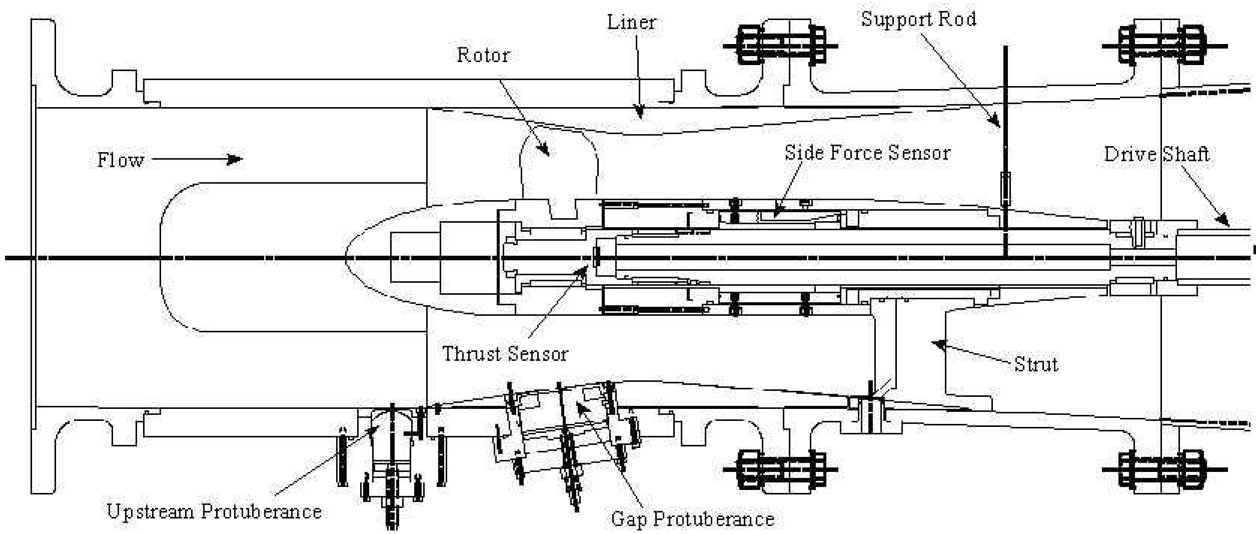
- **Influence of Gap Variation**
  - ➢ ***Lewis & Yeung('77) & Farrell('89) showed that the tip force on a rotor varies with uniform tip gap as $L = L_0 \exp(-14h/c)$***
  - ➢ ***Farrell('94) demonstrated that a circumferential variation in the gap around a shrouded fan by scalloping the endwall provided a means for noise reduction.***
- **Gap/Endwall Limitations**
  - ➢ ***Static endwall contours are good passive methods for BPF control, but trial and error is required to optimize contour.***
    - ■ **Any changes in the inflow will degrade the noise.**
  - ➢ ***Need an adaptable endwall contour that will deform to the proper shape.***
  - ➢ ***This technology was not readily available in the 1990's.***



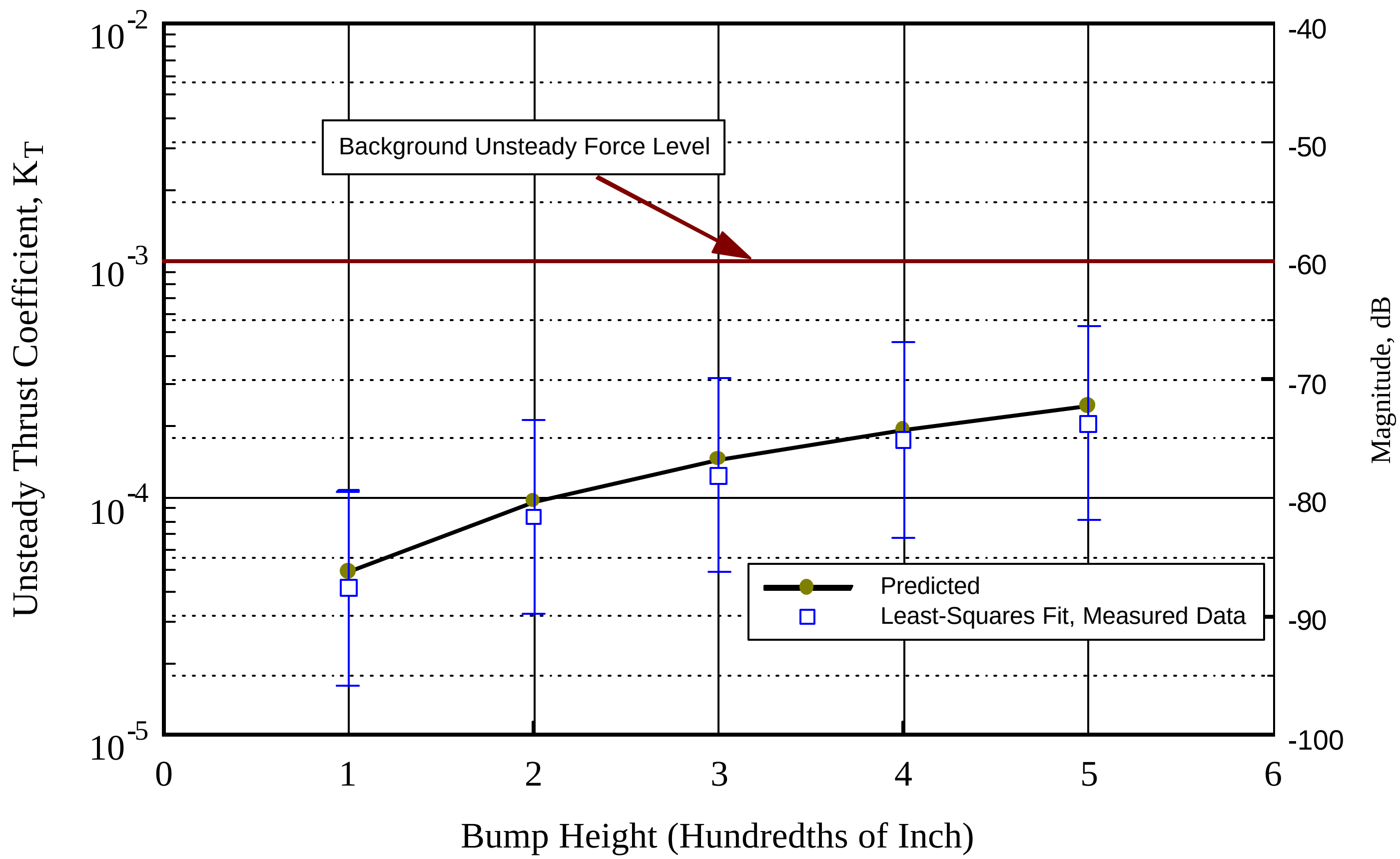
SAMPSON technology allows for a quasi-steady variation of the endwall contour to adjust the gap between the rotor tip and the endwall. Sensors measure the response and a controller commands actuators to make fine adjustments to the endwall contour.

Twelve-inch Water Tunnel Testing

- **Objective: Obtain quantitative information of the expected actuation strength of the gap variation on the unsteady thrust and compare to the predicted estimate**
- **Approach: Measure the unsteady thrust of a three-bladed rotor due to**
  - ➢ ***A single narrow protuberance and three broad protuberances***



Effect of bump height for a single narrow bump



Measured unsteady thrust for broad bumps higher than predicted levels

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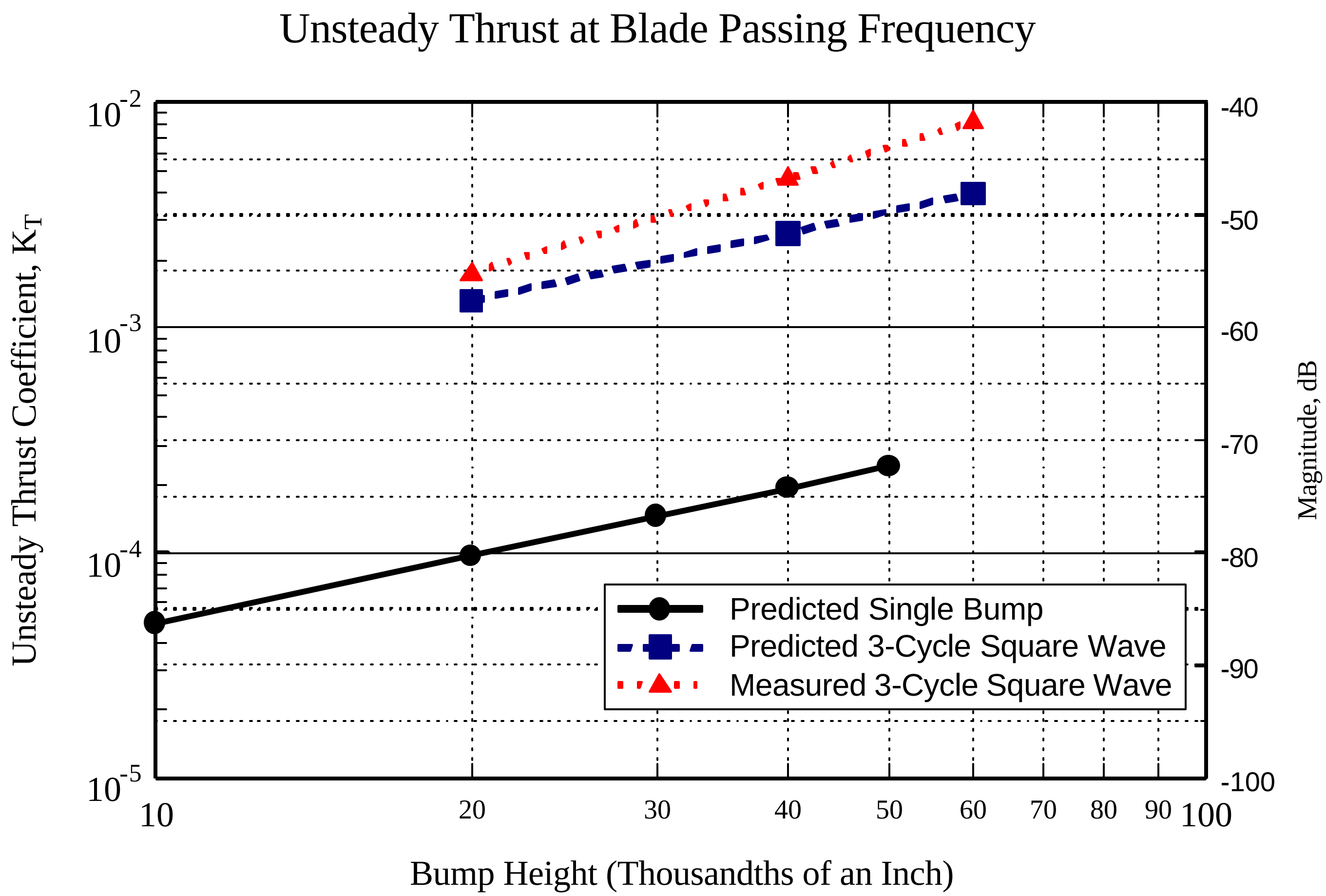
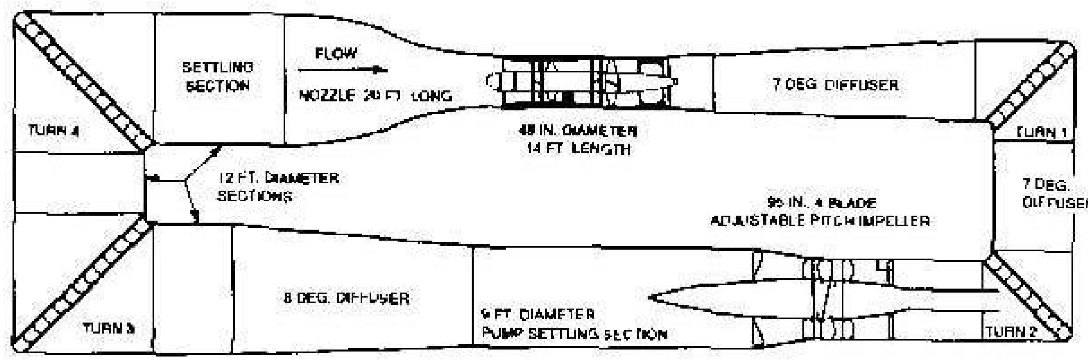
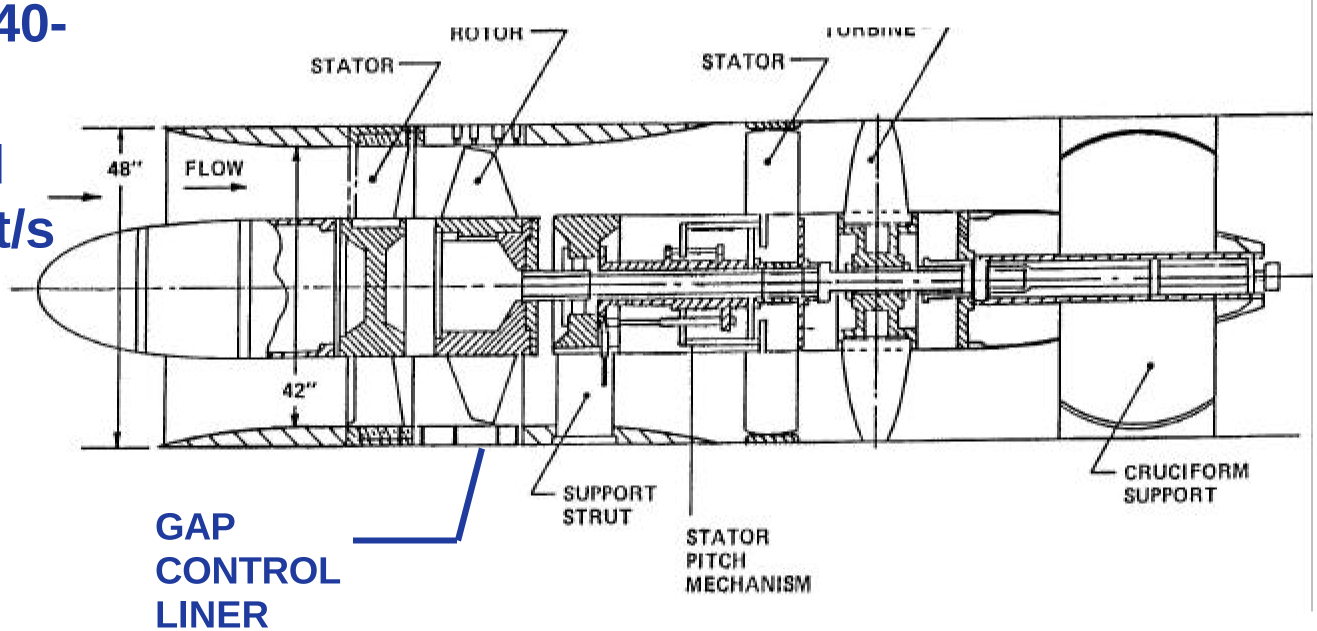


Final Demonstration-HIREP

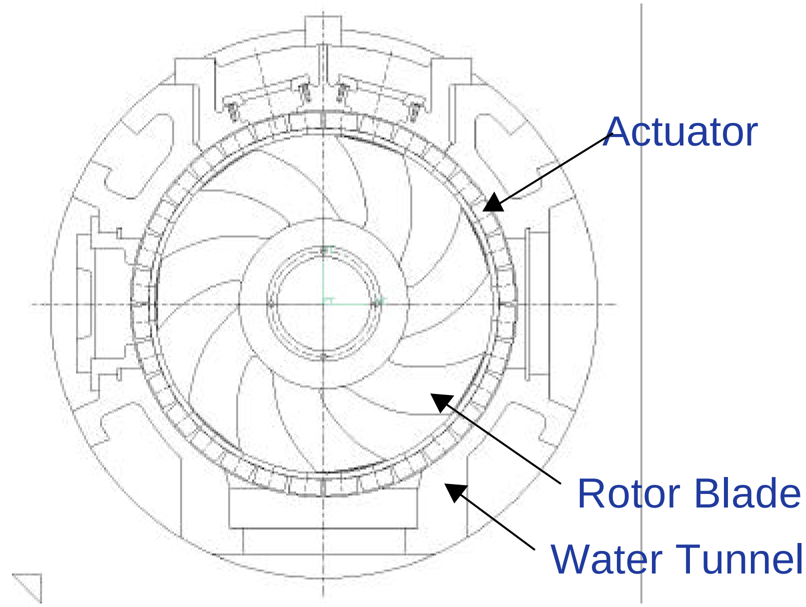
- Maximum Blade Reynolds Number of 6 Million
- 1200 HP Turbine Drive
- Variable RPM (40-400)
- Maximum Axial Velocity of 50 ft/s

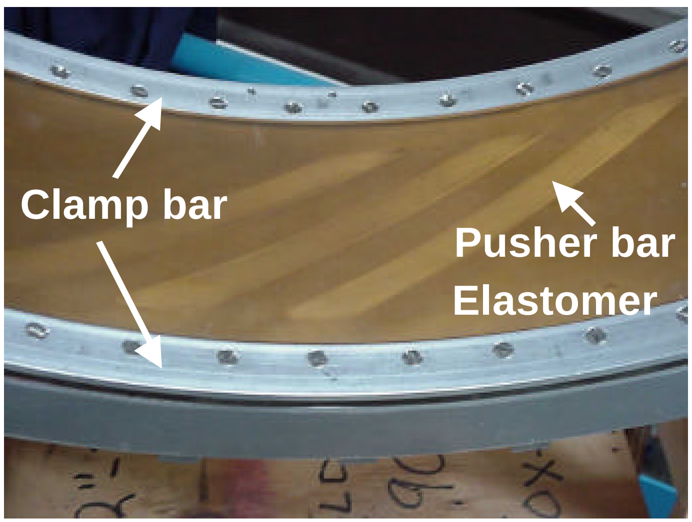


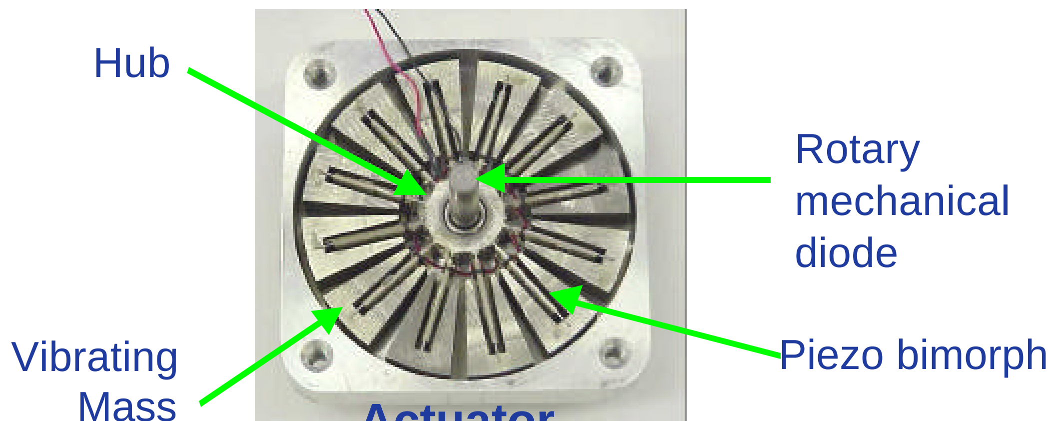


Gap Control Liner

- 32 Actuators
- Control of 1x and 2x BPF forces requires at least 31 actuators (Nyquist criteria)
- Superimpose many spatial orders to cancel all simultaneously



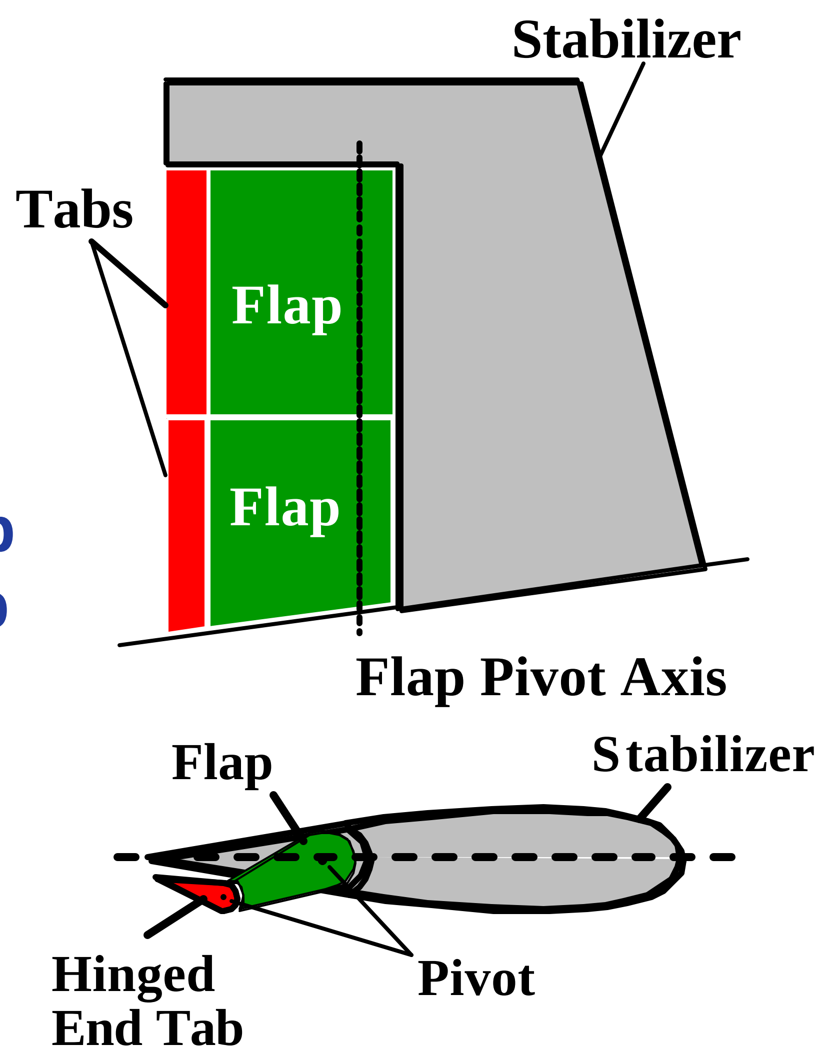




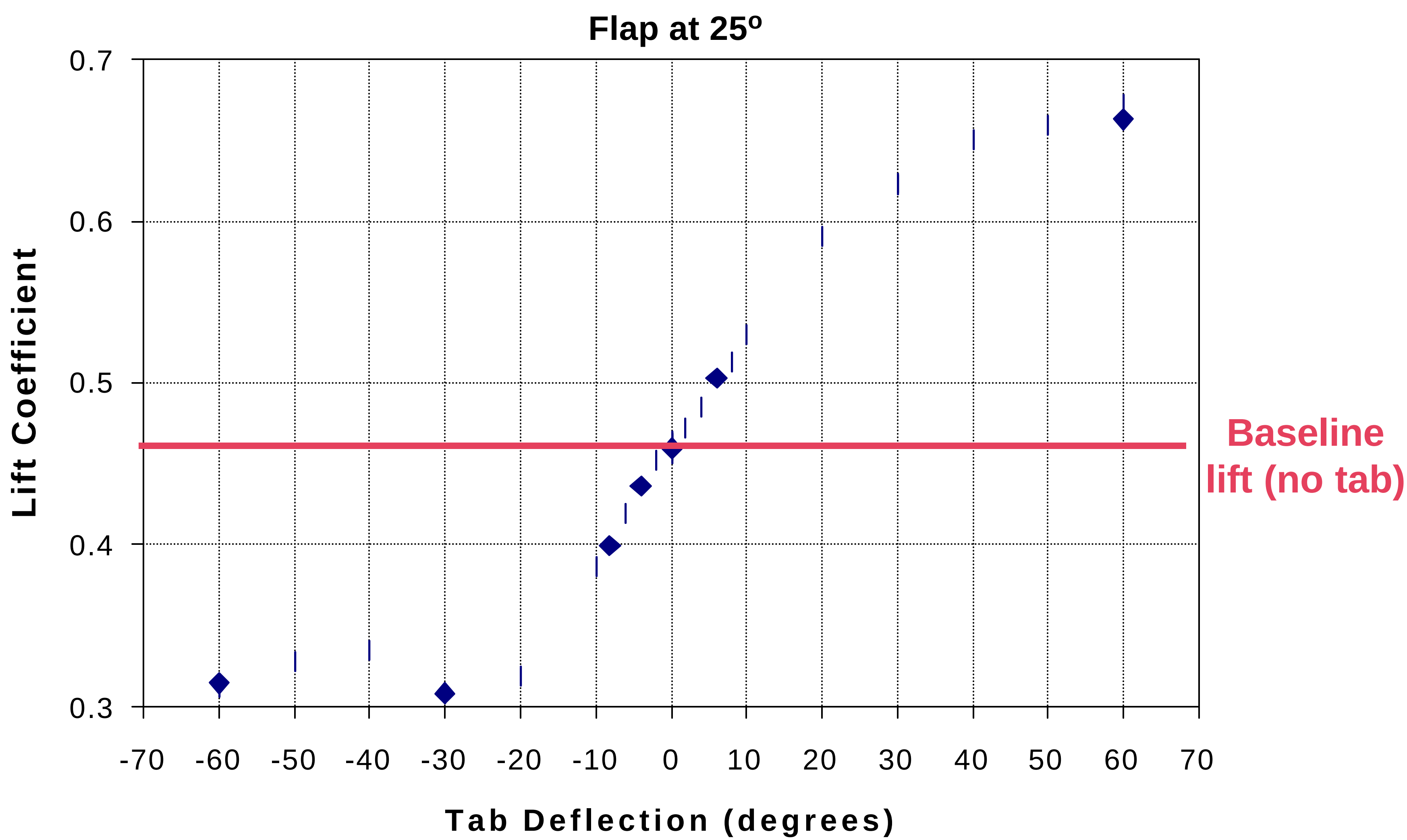
Actuator

TAC Concept - Trailing Edge Tab Added to Control Surface

Basic TAC Concept is to manipulate overall lift and flap center of pressure (hence flap torque).



Effect of TAC on Lift Coefficient



Effect of TAC on Torque Reduction

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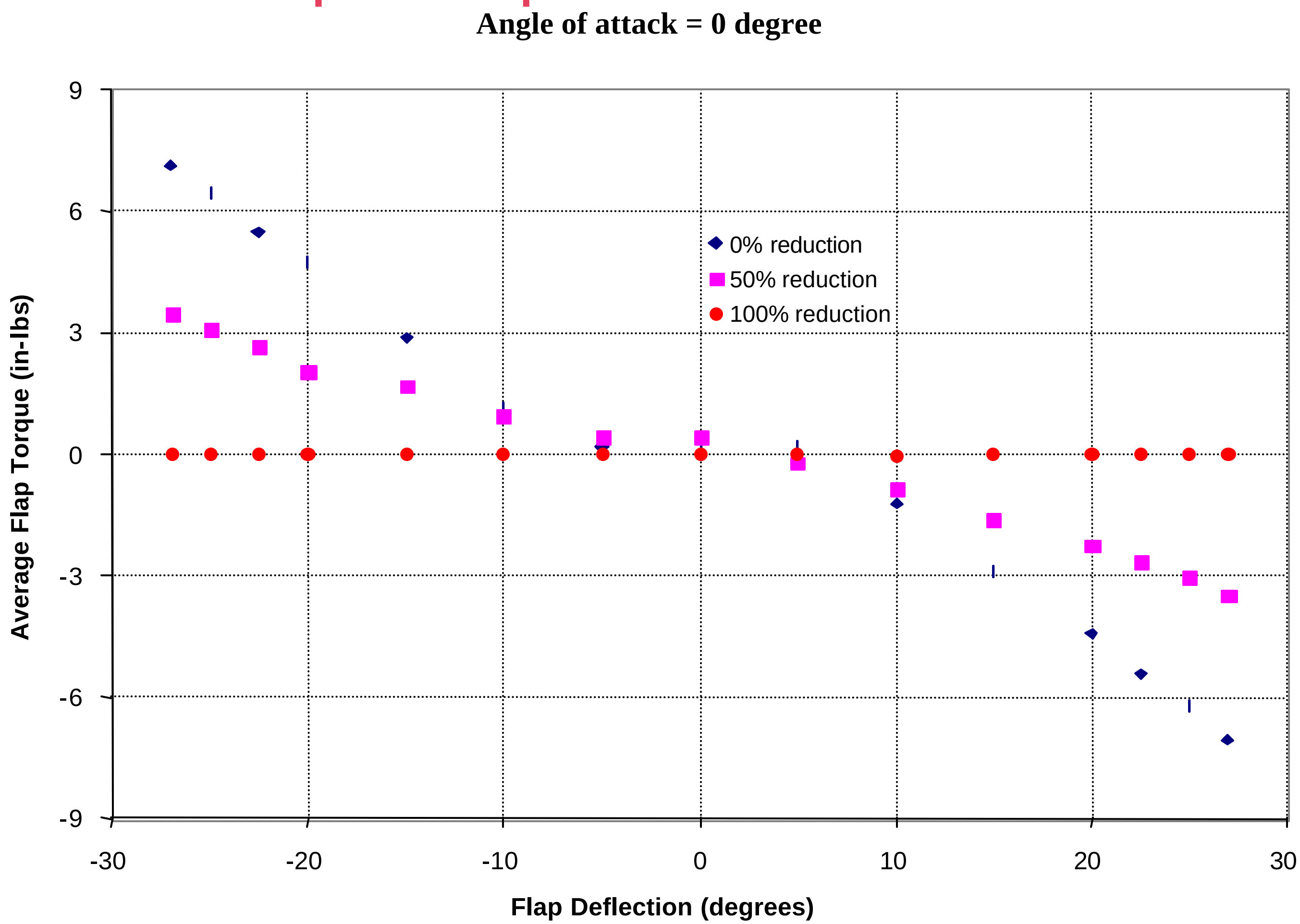
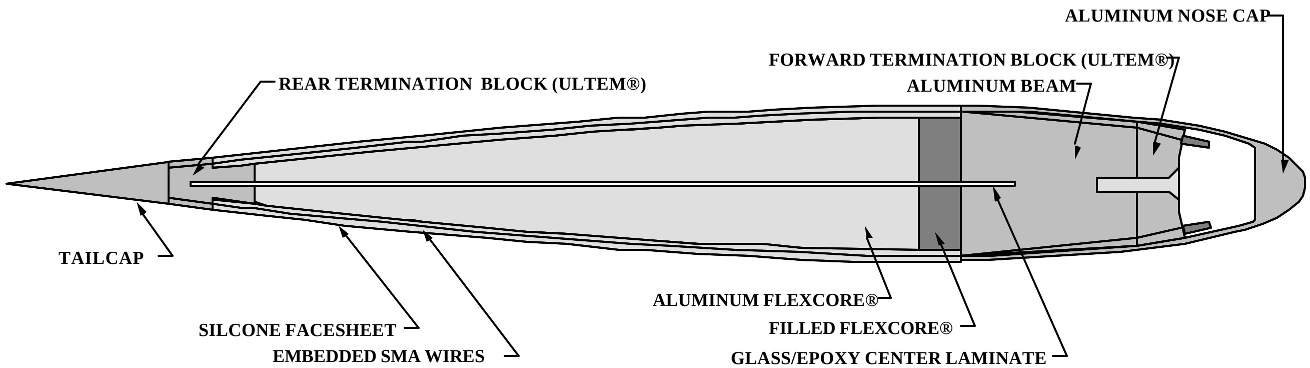
- **Over 95% reduction in power requirement.**



BAC / GDEB / PSU / LM / NASA / NSWC / GTE-BBN

Leverage DARPA SVLT Program



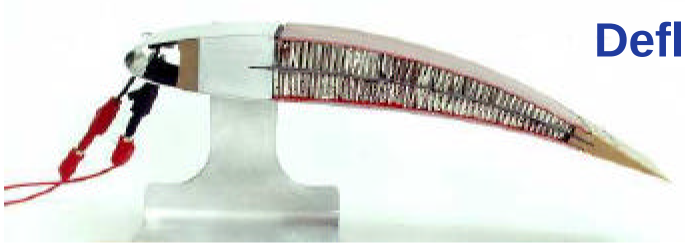
- Variable camber load control

Antagonist design offers rapid, two-way push-pull response

3" span 'model' SVLT

Undeflected

Deflected



- ➢ Total static deflection >1.5"
- ➢ Exceeded SVLT requirements

27" Span X 12" Chord Prototype

- ➢ Fabricated by LMA Denver (3/98-6/98)
- ➢ Water tunnel tested at NSWC/CD 10/98

Far-Term Vision

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- Control surfaces that are:
  - *Locally actuated*
    - Ability to easily relocate control surfaces (plug & play)
    - Free up space
  - *High lift and low power*
    - Low-speed maneuvering performance enhancement
    - Improved recovery
  - *Potential reduced cost*
    - Reduced construction and maintenance costs by removal of traditional control surface hardware

Current System - Global Hydraulic Actuation

Future System - Local Actuation

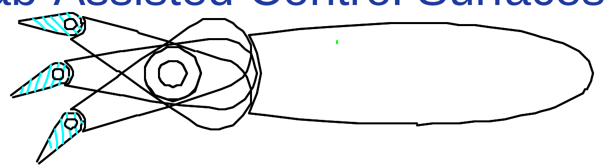
Far-Term Vision With Near-Term Products

Current Global Actuation Systems

Future Local Actuation Systems

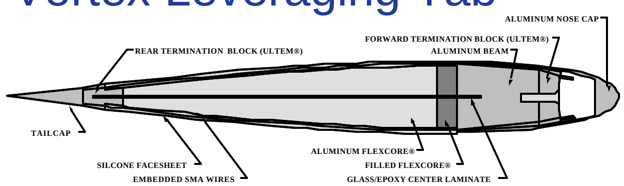
New Technologies:

- Tab-Assisted Control Surfaces (TAC)



FlexTAC will utilize TAC concept developed and tested in the DARPA SAMPSON/ONR ACS/TAC Programs.

- Smart Vortex Leveraging Tab

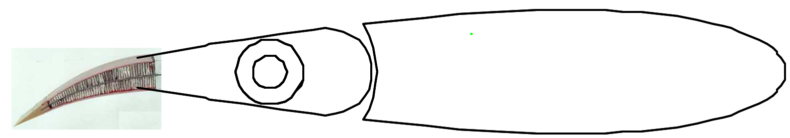


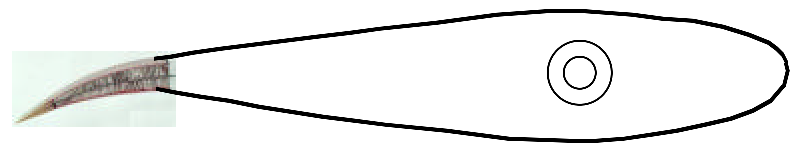
FlexTAC will focus on the Shape Memory Alloy (SMA) technology developed, implemented and demonstrated in the DARPA Smart Vortex Leveraging Tab (SVLT) Program

- Other actuation methods

Concept Off-Ramps:

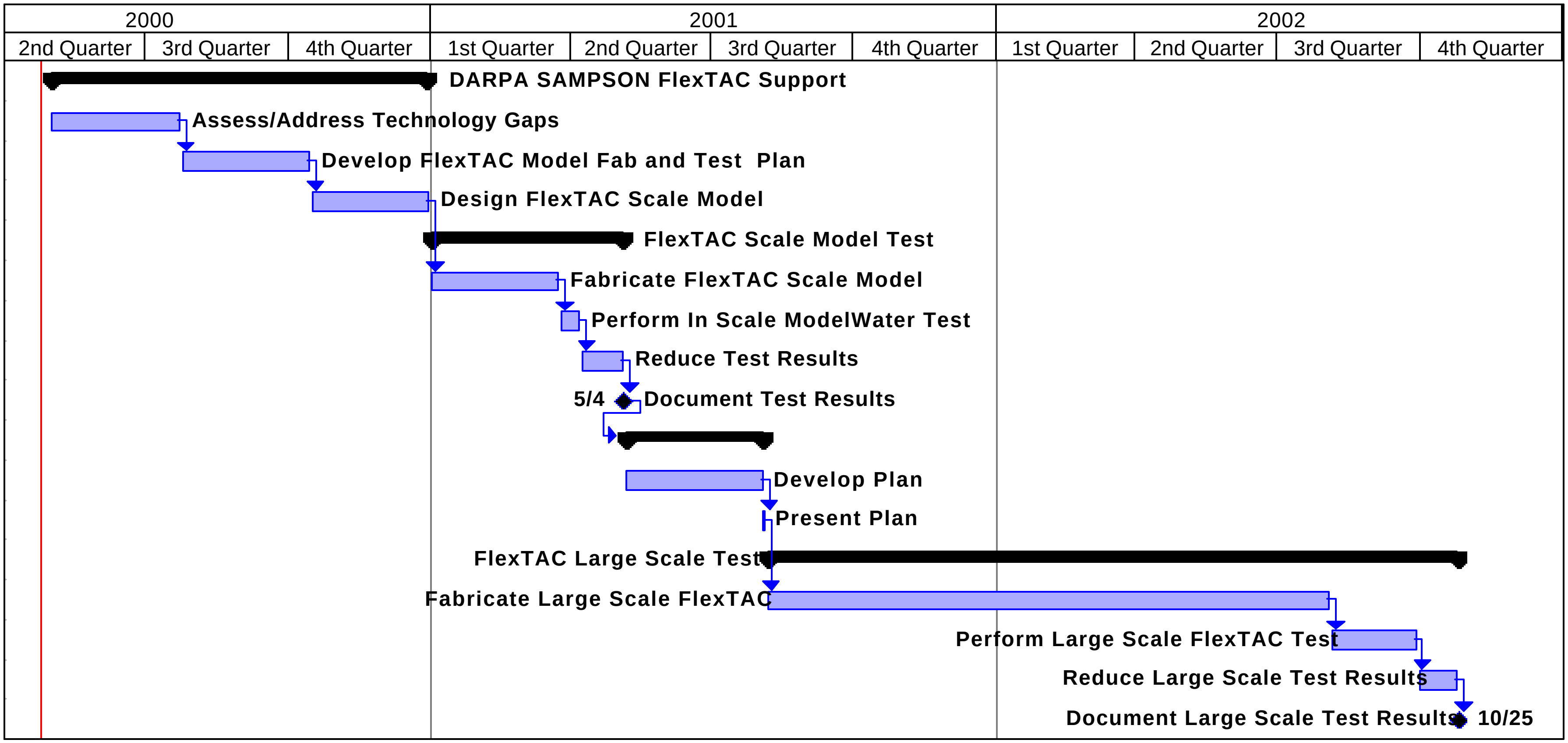
- FlexTAC





- Control surfaces without traditional steering and diving hardware (i.e., totally local actuation)

Proposed FlexTAC Schedule

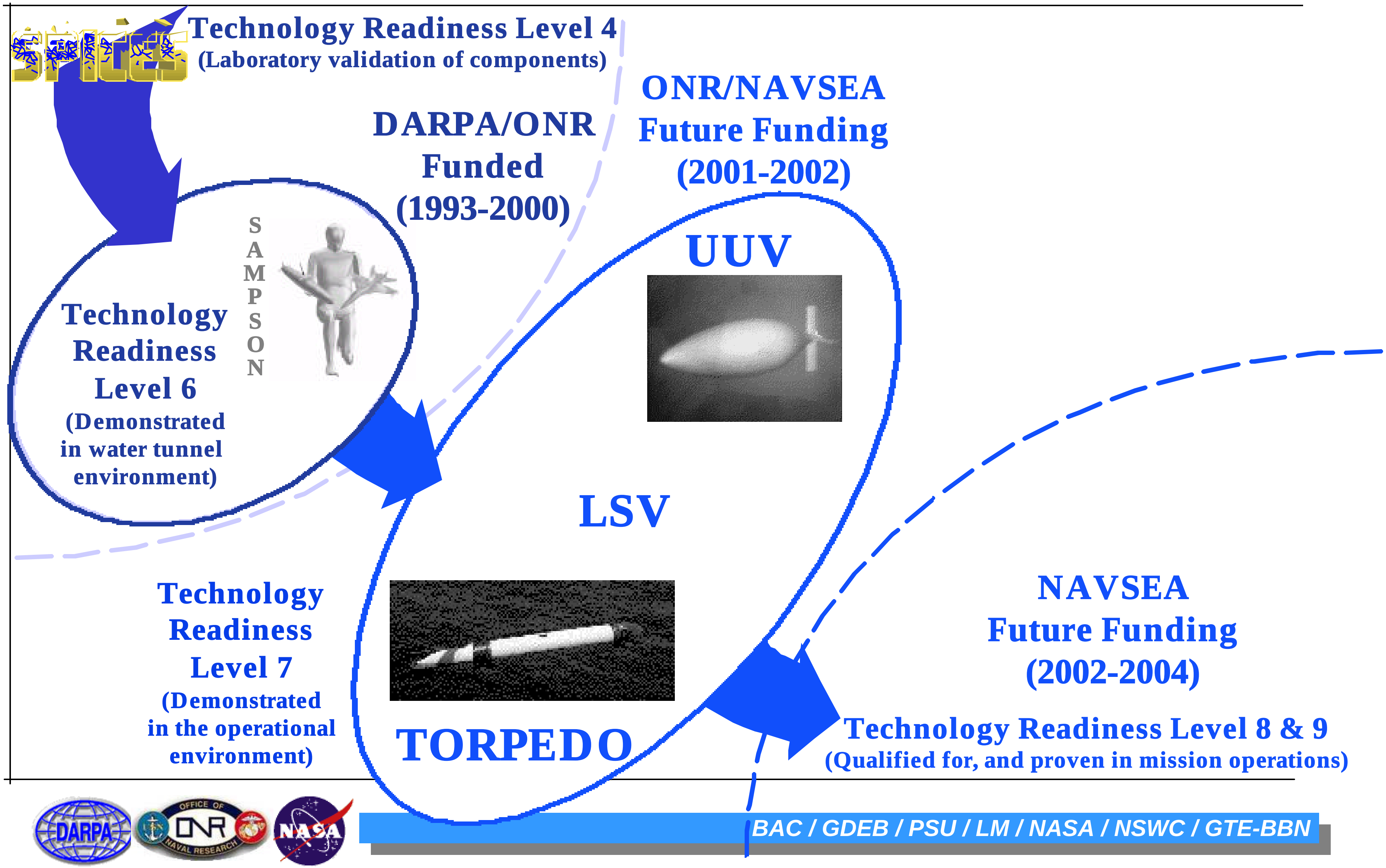


Accomplishments Since Last TIM

SAMPSON

- Gap Control Concept
  - *Presentation to NSWC/CD on Gap Control*
  - *Development of and Fabrication of Rotary Actuators for Gap Control*
  - *Development of Final Demonstration Test Plan and Schedule*
  - *Development of and Acquisition of Final Demonstration Control System Hardware and Software*
  - *SPIE Presentation*
  - *Completion of 3rd Water Tunnel Tests at PSU/ARL*
- Tab Assisted Control Concept
  - *Fabrication of SMA TAC Test Fixture & Test Plan*
  - *Development of Flexible TAC Concept and Plan*
    - Presentations to NAVSEA 93R, 05H and 05U on FlexTAC

SAMPSON Technology Transition Plan



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